Building the Case for Dams and Levees

Best Practices in Dam and Levee Safety Risk Analysis

Part A- Risk Analysis Basics

Chapter A-10

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US Army Corps of Engineers®

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

DEPARTMENT OF ENERGY FEDERAL ENERGY REGULATORY COMMISSION

TVA

Outline

- Objectives and Key Concepts
- Confidence in Claims and Uncertainty
- Arrange evidence to Support Argument
- Coherence Check

Objectives and Key Concepts

- Objectives – Learn how to build a case
  - Show how we:
    - Integrate Information into a Coherent Argument
    - Provide Evidence to Support an Argument
      - Focus on the most compelling evidence
    - Include Confidence in Claims
    - Coherence of risk estimates, case to support it, and recommended path forward
  - Show how “The Case” is more than just numbers

Decisions

- Typical Decision Makers
  - Varies by Agency
  - They rely on technical staff to build the case
- Five Pieces of Information to make the Case
  - Existing condition and ability to withstand future loading
  - Risk Estimate
  - Estimated Range of Uncertainty (and Confidence)
  - Case to Support Risk Estimate
  - Recommended Course of Action(s)
- Strategy
  - Use the risk estimate in relation to the risk guidelines and the safety case to support rational consistent decisions

Where we get the Evidence to Build Cases

- Case histories of failures and of successes
- Site characterization (geologic details)
- Empirical data
- Changes to design precedents
- Design details
  - Key defenses (multiple, many made to address past incidents)
  - Construction details
- Performance, good or poor (Instrumentation, flood fighting, seepage, cracking etc.)
- Inspections and observations
- Analysis
- Other PFMA's and risk analysis
- Poor performance at other structures today
- Construction photos and drawings

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Confidence and Uncertainty

- Confidence in claims made to build the case are derived from the logic of the arguments put forth and the strength of the evidence for claims made. This is demonstrated in examples provided below.
- When the confidence is low such that such that additional information could change the perceived risk either up or down we estimate the likelihood of changing the justification class using risk costs. These costs form the basis of a risk informed decision.
- Uncertainty in building the case is expressed as a range of the mean or expected values and is demonstrated in the following examples as well.

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Building the Case

$$\text{Risk} = \sum \begin{bmatrix} \text{Probability} \\ \text{of the Loading} \end{bmatrix} \begin{bmatrix} \text{Probability of Failure} \\ \text{Given the Loading} \end{bmatrix} \begin{bmatrix} \text{Consequences} \\ \text{Given Failure} \end{bmatrix}$$

Teams must build the case for each of the three inputs to a risk estimate for all potential failure modes. Provide the evidence for these inputs.

Stating key parameters, model limitations and assumptions that drive the result is important for all three parts in building the case.

Building the Case

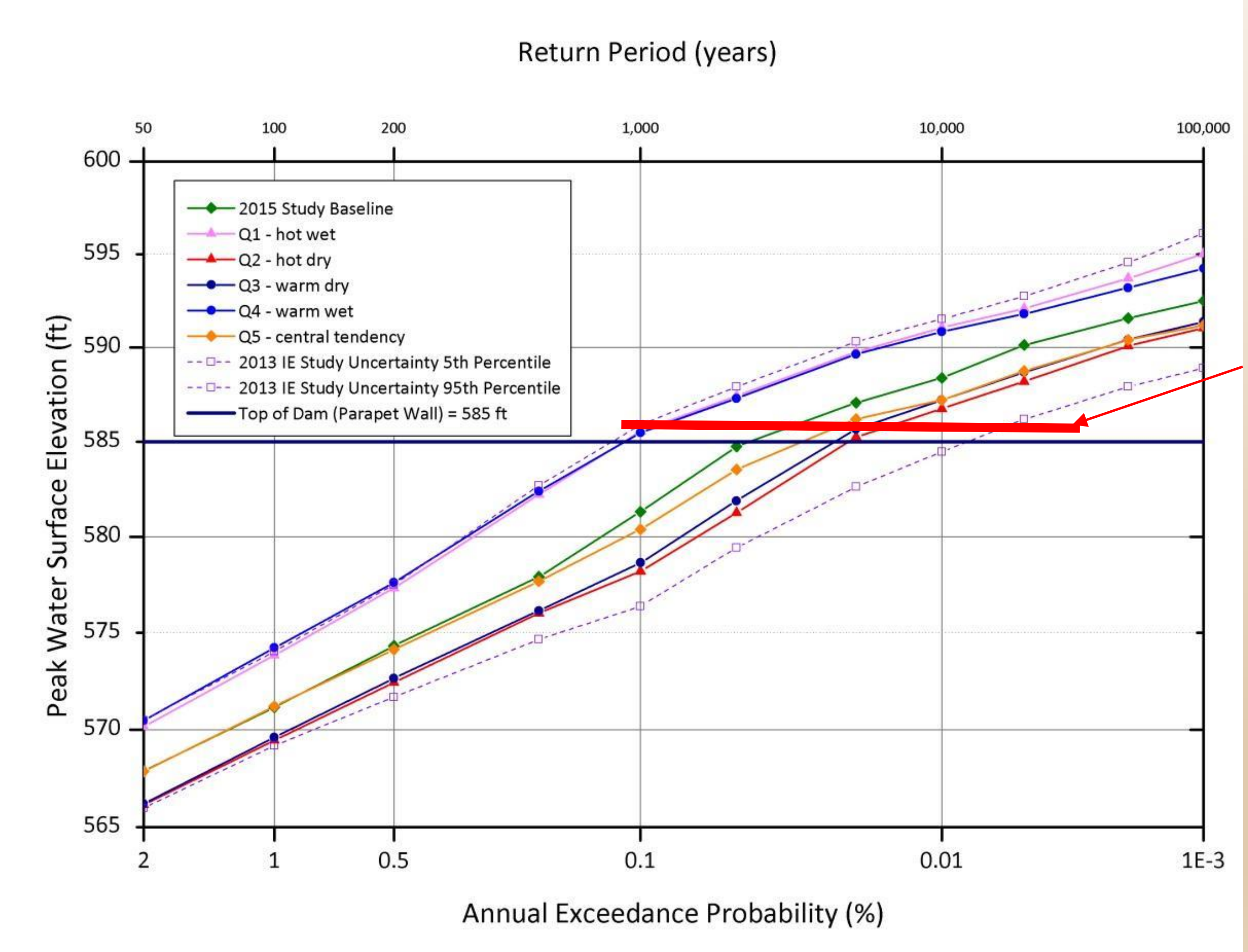
$$\text{Risk} = \sum \begin{bmatrix} \text{Probability} \\ \text{of the Loading} \end{bmatrix} \begin{bmatrix} \text{Probability of Failure} \\ \text{Given the Loading} \end{bmatrix} \begin{bmatrix} \text{Consequences} \\ \text{Given Failure} \end{bmatrix}$$

Teams must build the case for all potential failure modes.

What are the essential elements of building the case for the loading estimate?

Pool Frequency Relationship w/ Uncertainty

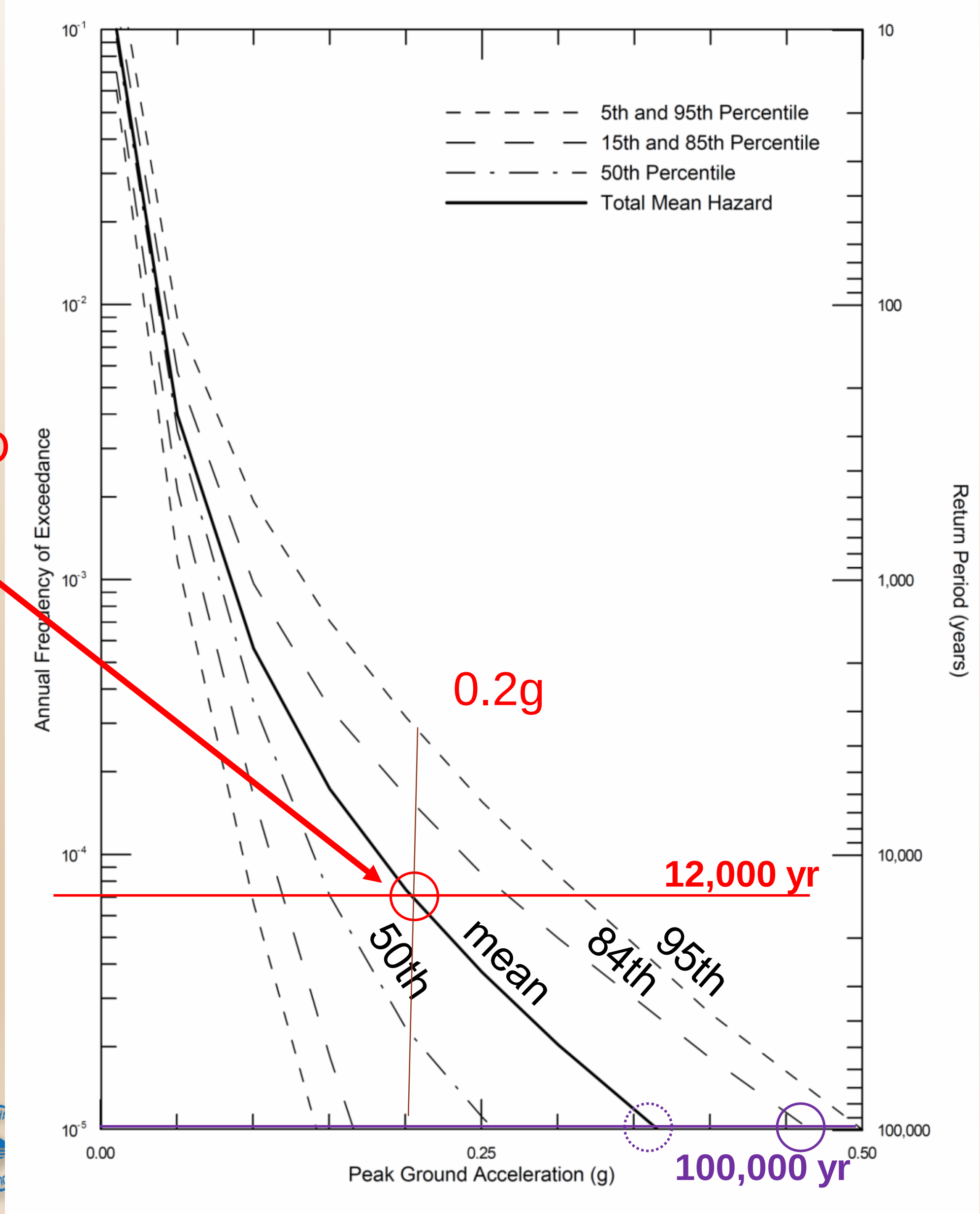
- Uncertainty of peak flow frequency with paleofloods
- Uncertainty of basin-average rainfall frequency
- Variation in rainfall-runoff parameters and inputs
- Discuss why the shape and magnitude of the hazard curve make sense
- Show how different lines of evidence corroborate each other.



SHOW THE THRESHOLD

Site-Specific Seismic Hazard Curve

SHOW THE THRESHOLD EVENT



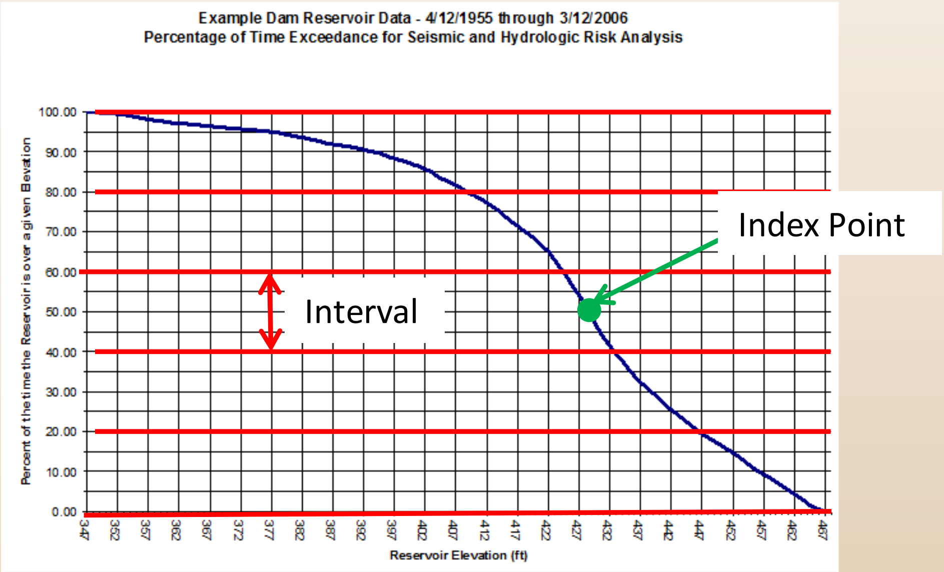
Annual Exceedance Probabilities (AEP)

For risk assessment

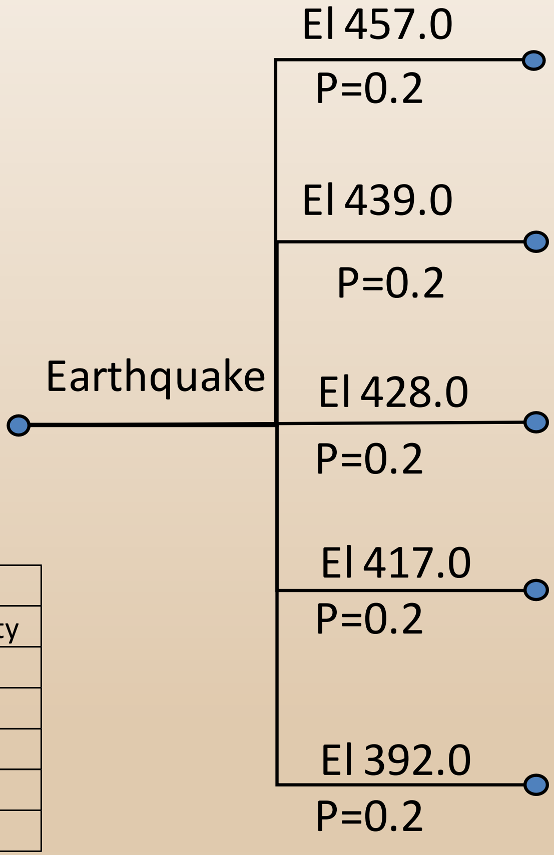
- 2,475 yr GM (AEP=4xE-04)
- 9,975 yr GM (AEP=1xE-04)
- 100,000 yr GM (AEP=1xE-05) (if GMPE allow)
- 50th or 84th percentile

Coincident Events - Example of EQ and Reservoir Level

- Point out where coincident events are needed for failure to occur
- Other examples may include gate reliability and spillway erosion



Elevation			Fraction of Time Exceeded		
Lower Bound	Upper Bound	Index Value	Lower Bound	Upper Bound	Probability
447.0	467.0	457.0	0.2	0	0.2
432.0	447.0	439.0	0.4	0.2	0.2
424.0	432.0	428.0	0.6	0.4	0.2
409.0	424.0	417.0	0.8	0.6	0.2
347.0	417.0	392.0	1	0.8	0.2

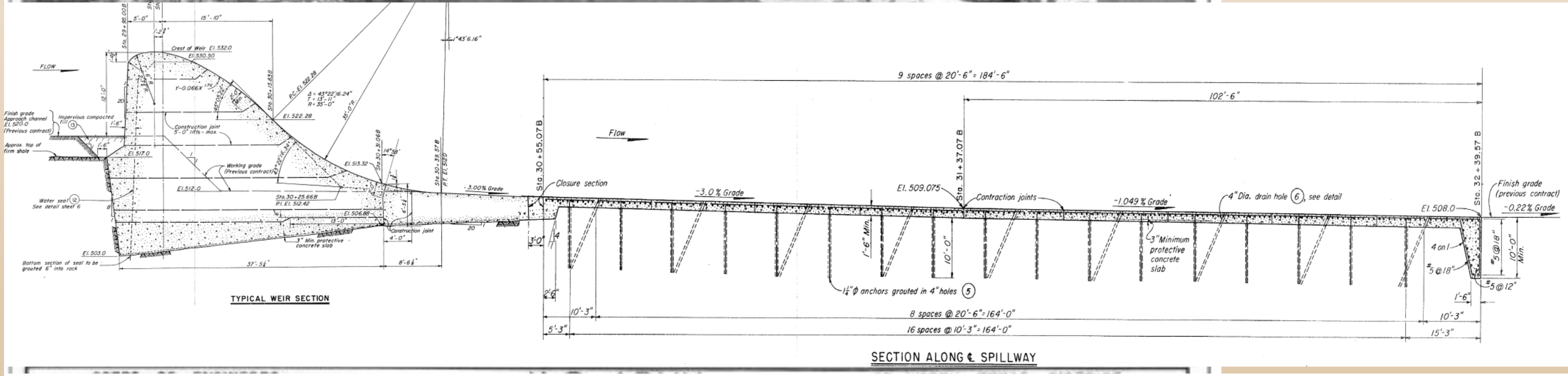


Building the Case

$$\text{Risk} = \sum \begin{bmatrix} \text{Probability} \\ \text{of the Loading} \end{bmatrix} \begin{bmatrix} \text{Probability of Failure} \\ \text{Given the Loading} \end{bmatrix} \begin{bmatrix} \text{Consequences} \\ \text{Given Failure} \end{bmatrix}$$

Teams must build the case for all potential failure modes.

Given the loading, what are the essential elements of building the case for the probability of failure?



Multi-discipline example that requires multiple lines of evidence

PFM 7 Spillway weir instability due to failure of the spillway apron slabs during high velocities and high stagnation pressures in the existing offset joints in the apron slabs leads to sliding of the spillway weir and uncontrolled loss of reservoir.

Building the Case

Event(Node) 2

Claim – high velocity flows and stagnation pressures uplifts a slab

Figure 9-43: Photo of existing 1”(+) offset along a spillway apron slab joint which could induce stagnation pressures

*There are no dowels or any type of interlocking system between slabs along joints.

Mean Uplift Pressure, sharp edged geometry, sealed cavity, 1/8-inch gap

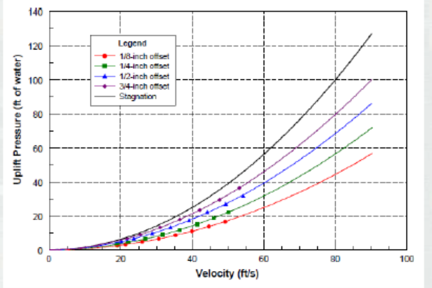


Figure 9-59: Best Practices USACE/USBR Stagnation Pressure Relationship to Flow Velocity

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Claim - The exposed found. scours and erodes leading to progressive failure of upstream slabs to the toe of the crest structure

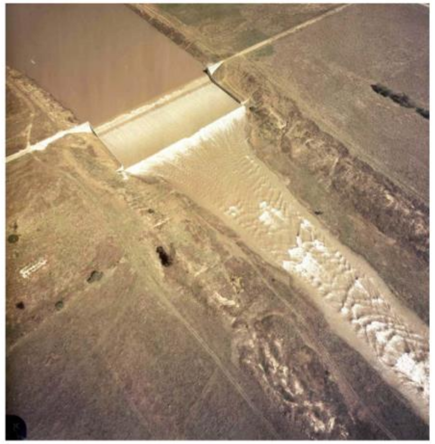

Figure 2-16: Lewisville Dam. Turbulent flow in the spillway channel just downstream of spillway weir resulted in severe erosion (Photo taken around October 1981)

*The 1982 event was reported to have eroded 7-8 feet at the downstream end of the spillway slabs.

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Claim - A crack along the u/s face results uplift pressures on the structure. Foundation shear resistance exceeded and monoliths displace

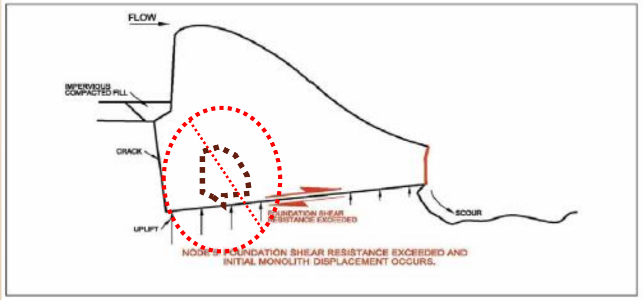

Figure 9-48: PFM 7 Progression Leading to Failure of Weir Monolith

*The risk of safety factors below 1.0 with no slab resistance reach, or nearly reach 100% as the uplift and pool event/ headwater increase.

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Claim - 3-D resistance Along vertical monolith joints are exceeded, displacements continue and breach occurs

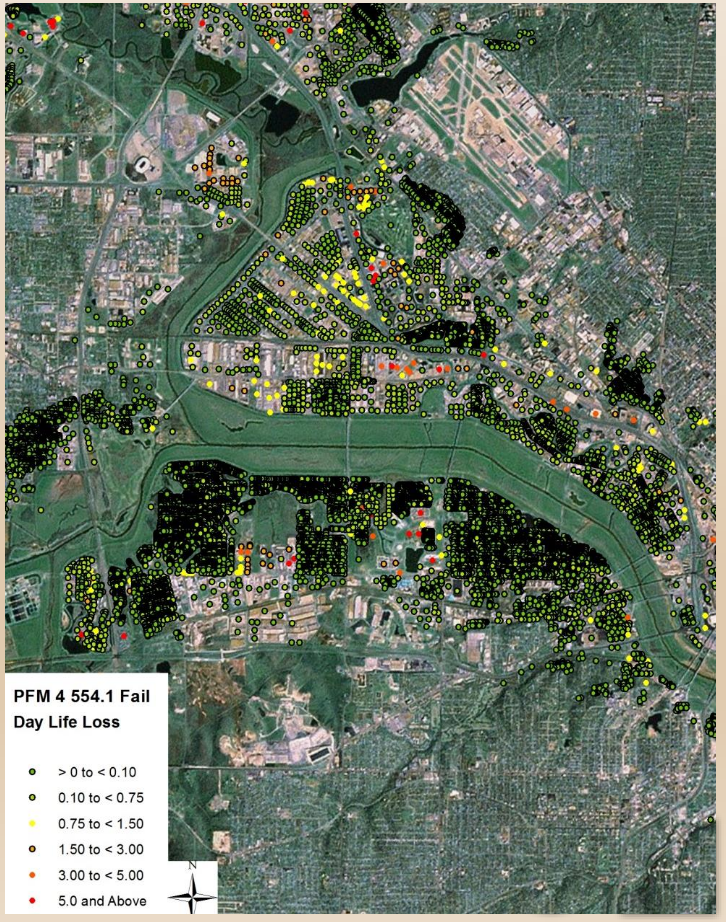
Building the Case for Consequences

$$\text{Risk} = \sum \begin{bmatrix} \text{Probability} \\ \text{of the Loading} \end{bmatrix} \begin{bmatrix} \text{Probability of Failure} \\ \text{Given the Loading} \end{bmatrix} \begin{bmatrix} \text{Consequences} \\ \text{Given Failure} \end{bmatrix}$$

Teams must build the case for consequences as rigorously as done for potential failure modes.

What are the essential elements of building the case for the consequence estimate?

- How many people are exposed to the flooding?
  - Initial distribution of people
  - Redistribution through evacuation
- How severe is the flooding?
- Are the people in a structure that can withstand the flooding?
- What is the likelihood people subjected to flooding will lose there life?



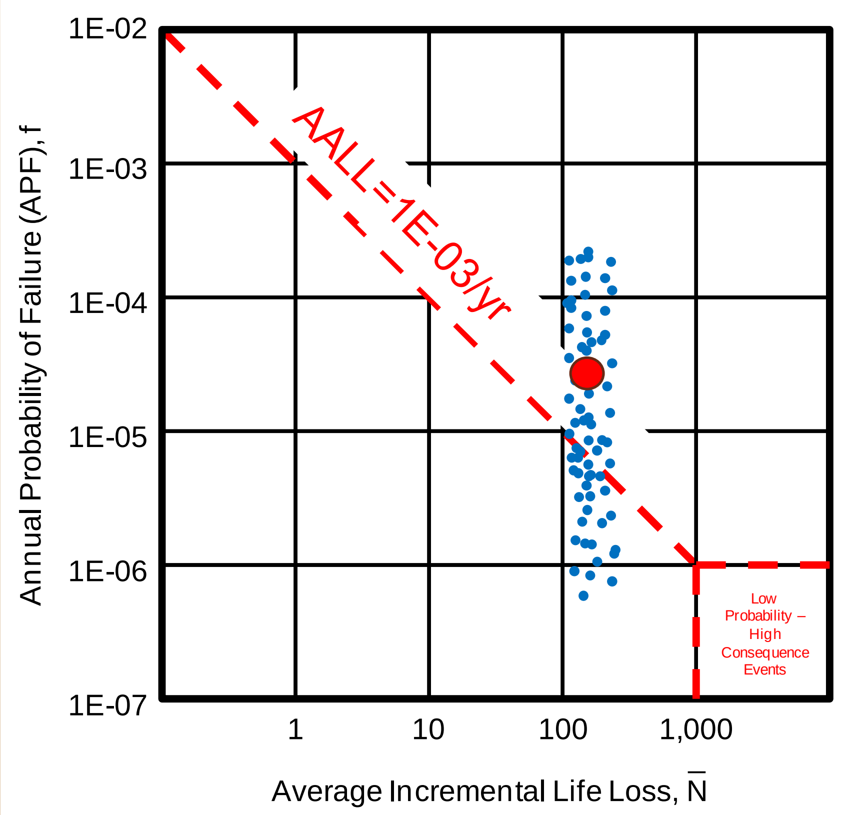
Making Sense of Detailed Consequence Analysis Results

- Characterize Flooding
  - Present assumptions regarding breach time/size, arrival time, depths and velocities, rate of rise
- Population at Risk
  - Location of PAR relative to dam or levee, and attributes of PAR (permanent, transient, rural, urban,etc.)
- Detection, Warning, Flood Wave Travel Time
  - Provide expected /best case/worst case assumptions on detection, decision to notify, notification process, decision to evacuate, evacuation process. Why is expected result where it is?
- Results
  - Show how many & where & sensitivity to assumptions

Arguments – For Further Study

- Estimated risk justifies risk reduction actions
- Investigations recommended to Reduce Uncertainty
- Any actions proposed based on uncertainty must address the sensitivity of the mean risk estimate to that uncertainty
- Moving the mean estimate changes the justification category
- There is a high likelihood the recommended investigation can reduce the uncertainty

Example – For Investigations



Blow Count

Mean: 16

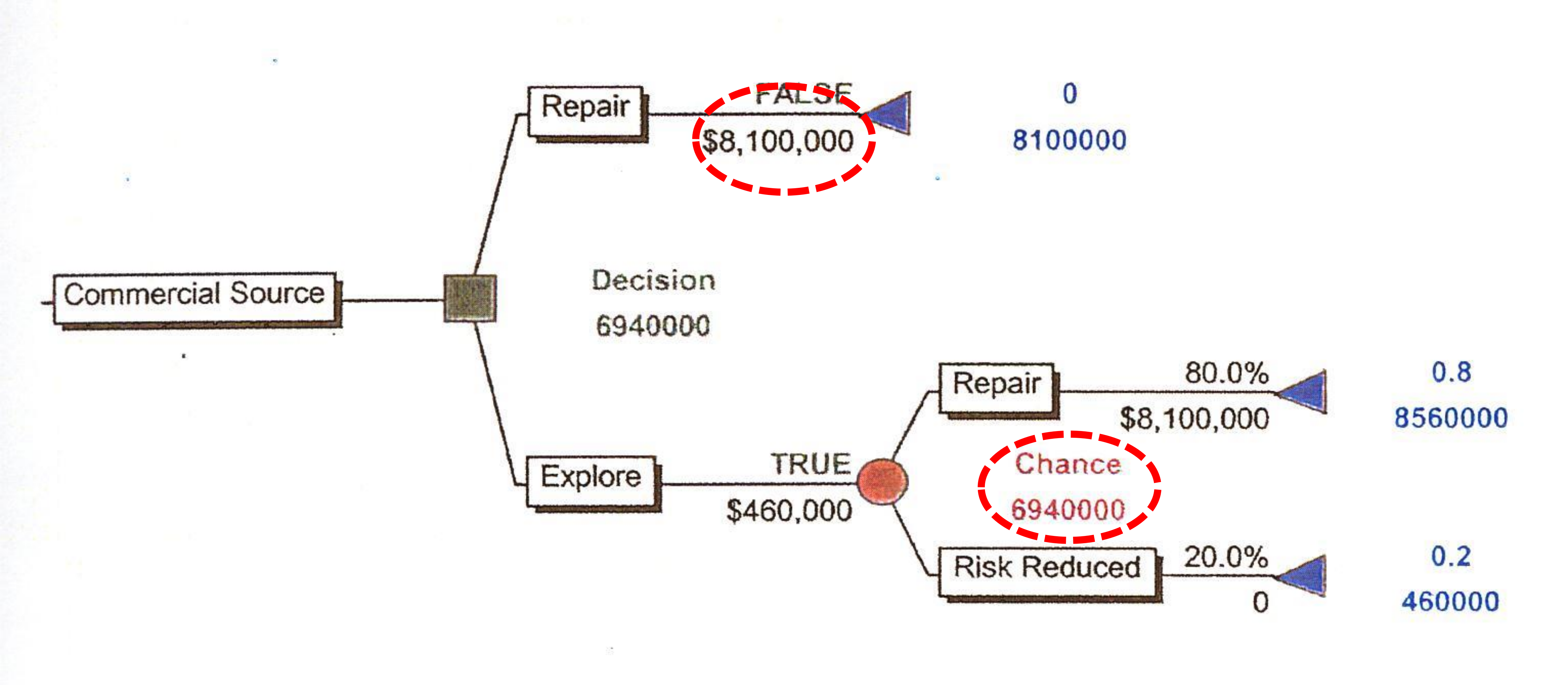
Std. Dev.: 8

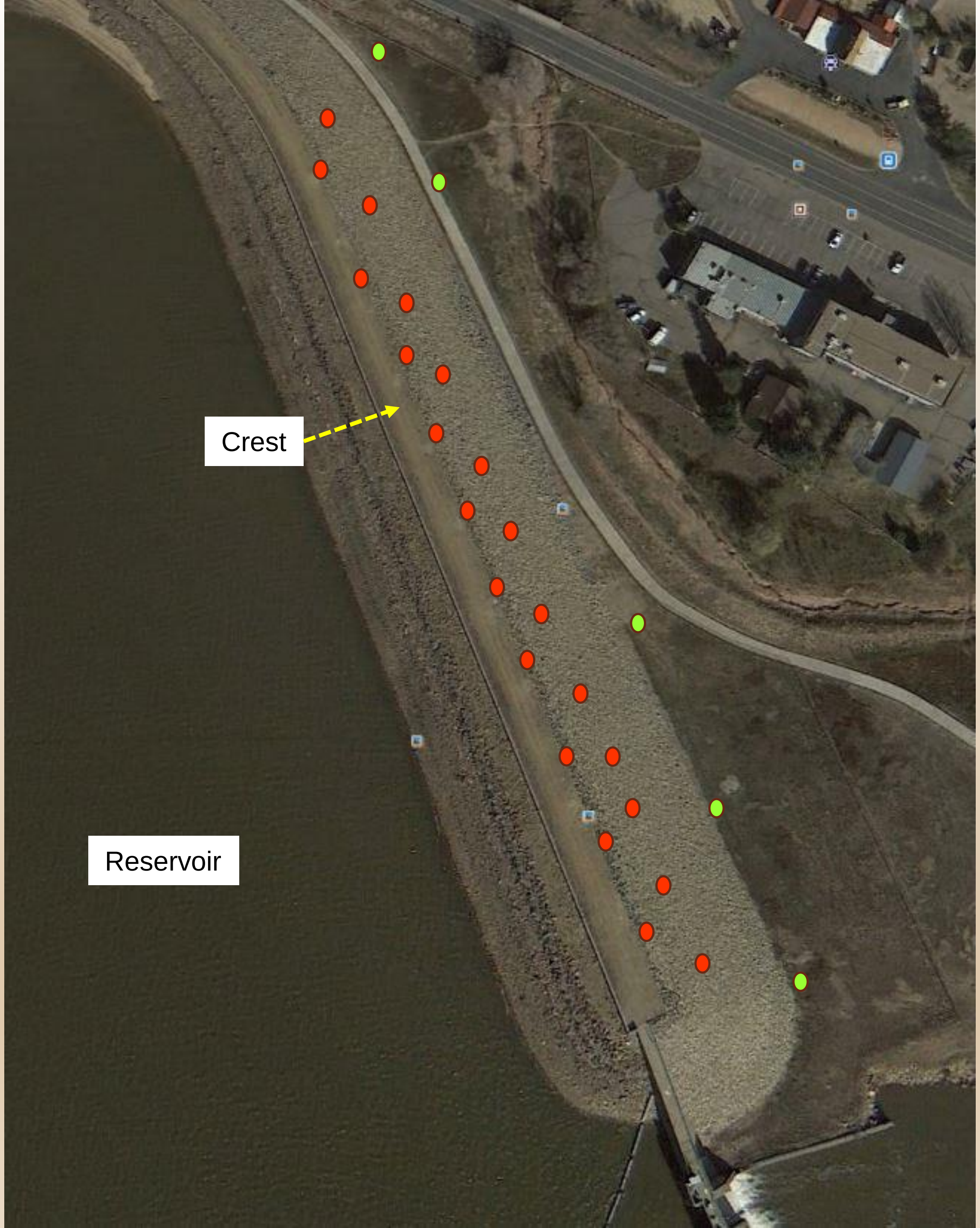
Six Boreholes

Unfortunate Locations

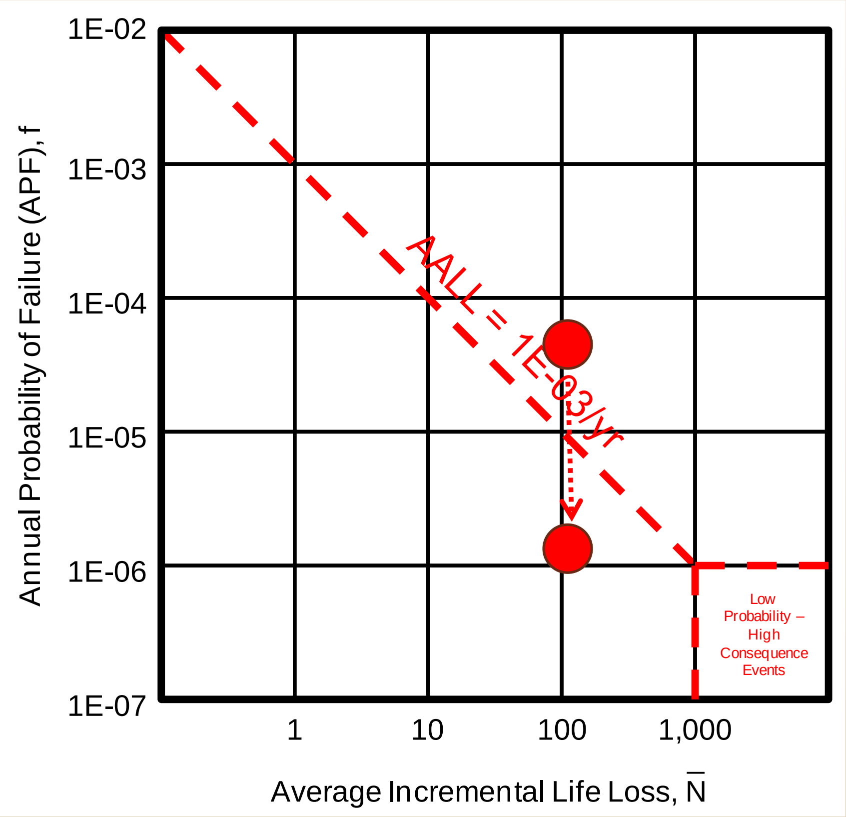
Blowcount 16 OK

Low Blow Count Hits Drove Up The Risk


Repair
FALSE
$8,100,000
0
8100000
Commercial Source
Decision
6940000
Repair
80.0%
$8,100,000
0.8
8560000
Explore
TRUE
$460,000
Chance
6940000
Risk Reduced
20.0%
0
0.2
460000

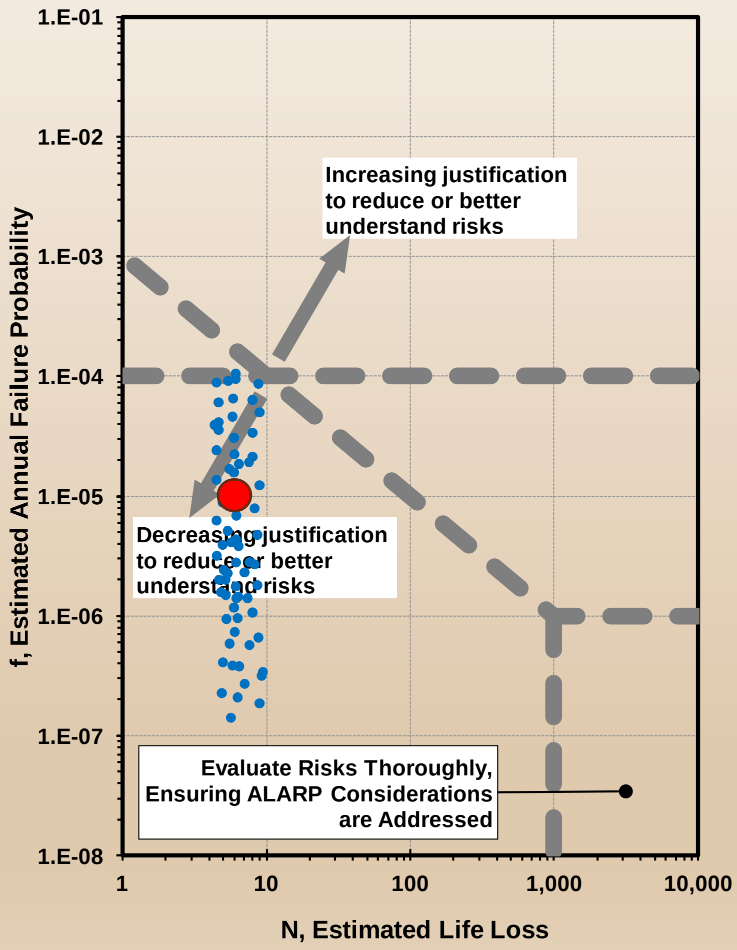

Crest
Reservoir

Incremental Life Safety Risk Matrix



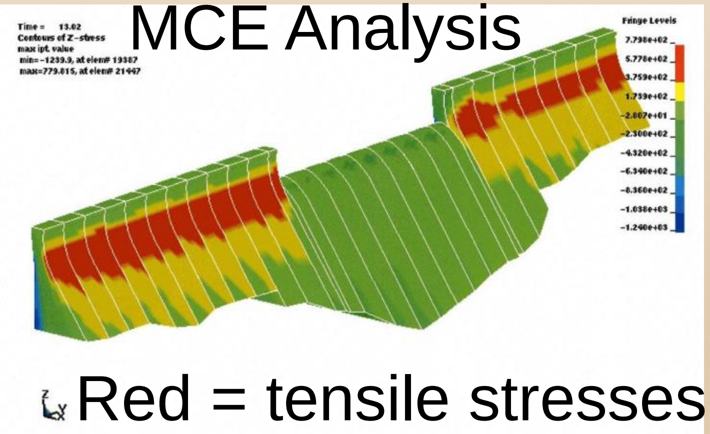
Arguments – Taking No Action

- Estimated risk is tolerable.
- Consideration of uncertainty related to the mean or expected value supports risk are tolerable.
- Confidence is high that no further studies will change findings.

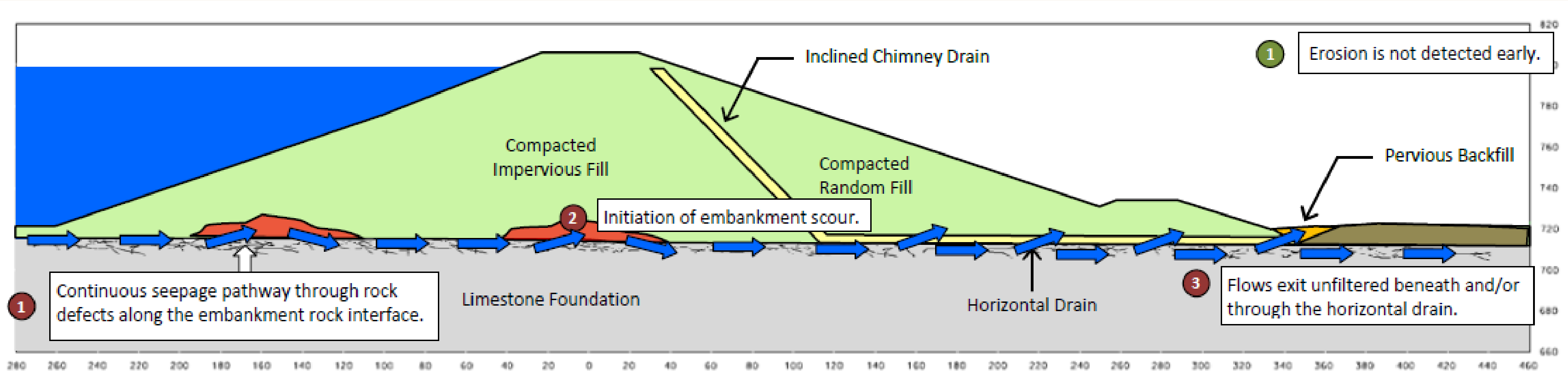


Build the Case

- Claim:
  - The lift joints near the spillway crest are well bonded and have significant strength. This leads to a low likelihood (0.1 or less) of cracking through the section at 1/10,000 AEP or smaller ground motions.
- Evidence:
  - No evidence of leaking lift lines in the critical area
  - All lift joints near the spillway elevation were recovered intact in core drilling
  - There were a large number of tests indicating high tensile strength across joints (report numbers)
  - Construction control procedures were excellent (describe)
  - Stresses less than estimated strength across the block (enumerate)



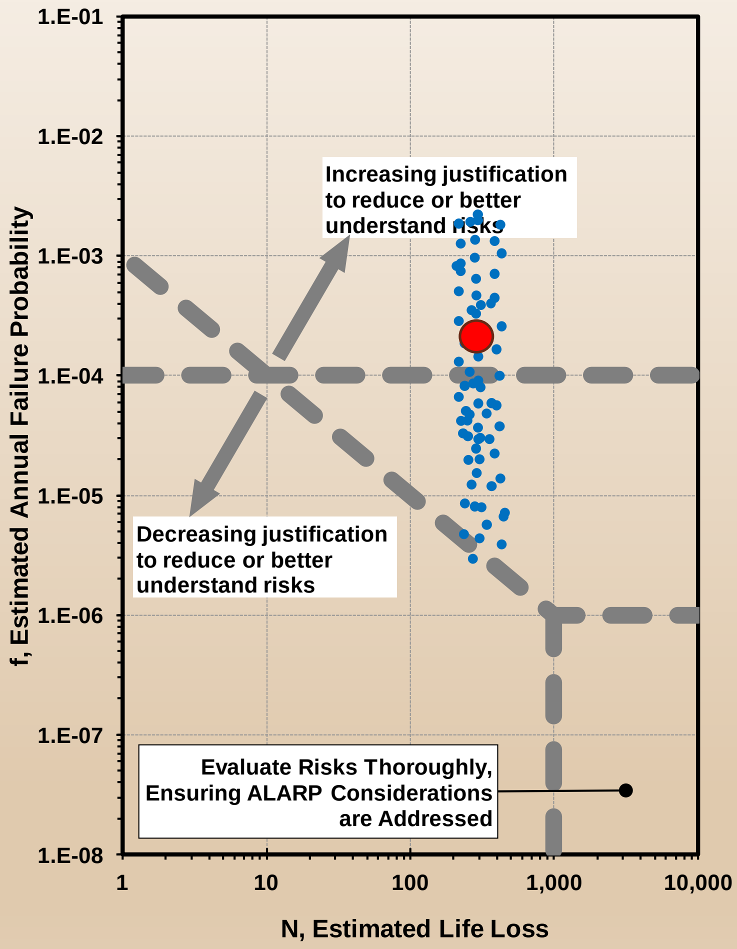
Building the Case for No Action



- Claim:
  - Chimney drain material filters the impervious fill. This along with other favorable factors leads to a low likelihood of failure.
- Evidence:
  - Gradation tests show filter criteria met (provide figure)
  - There were a large number of tests (report number)
  - Zone 2 material doesn't easily segregate (calculation)
  - Construction control procedures were excellent (describe)

Arguments – For Taking Action

- Estimated risk justifies risk reduction actions
- Consideration of uncertainty related to the mean or expected value supports risk reduction actions
- Confidence is high so no further studies are necessary



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- Arrange evidence to Support Argument
- Confidence in Claims
- **Coherence Check**

Some Key Questions

- Are the risk analysis and associated uncertainty adequately explained and portrayed? Do the portrayal and level of risks agree with your understanding of the project’s condition and its ability to withstand potential loads, based on the information provided? What key information leads you to believe the risk estimates are reasonable (or not)?

- Do the level and portrayal of risks support taking action to reduce or better define risks, and do they support the proposed recommendations as outlined in the report, based on the information provided? Why or why not?

Take Away

- Dam Safety Case – structured arguments developed to have the facility's condition, risk estimates, and recommended actions make sense
- Show the evidence as to why it is reasonable to believe the Risk and APF numbers. Do not use the risk value as sole basis.
- Fully develop the justification to take action (or that no action is needed)
- Address the sensitivity of the mean to key parameters, the likelihood a change justification class, and likelihood of success when recommending additional studies to reduce uncertainty

Cite the evidence that supports the case for why the risk estimates make sense and therefore why the recommendations make sense.

probability of loading

likelihood of failure

consequences